Egypt. J. Agron. **Vol. 47**, No. 4, pp: 895 - 913 (2025)

Egyptian Journal of Agronomy
http://agro.journals.ekb.eg/

Reduced herbicide doses in combination with boiled sorghum and mustard crop residues suppress weeds and increase yield in transplanted *aus* rice

Md. Towkir Ahmed [a, b], Mansura Khatun [a], Md. Shafiqul Islam[a], Uttam Kumer Sarker [a], Md. Abdus Salam [a] and **Md. Romij Uddin [a]**

[a] *Department of Agronomy, Bangladesh Agricultural University, Mymensingh 2202, Bangladesh*
[b]*Sustainable Agrifood Systems (SAS) Program, International Maize and Wheat Improvement Center (CIMMYT), P.O. Box 6057, Gulshan-1, Dhaka 1212, Bangladesh*

THE AGRICULTURE sector is constantly adopting environmentally friendly and sustainable methods to reduce the harmful effects of herbicides on crop production. In this phenomenon, two experiments were conducted at the Agronomy Field Laboratory (AFL) of Bangladesh Agricultural University (BAU), Mymensingh, Bangladesh during *aus* rice growing season (May to September) of 2022 and 2023 to evaluate the effect of allelopathic boiled extract of sorghum and mustard crop residues combined with reduced doses of herbicide (Granite 240 SC, a.i. Penoxsulam) in transplanted *aus* rice (T. *aus* rice). In the first-year experiment, treatments comprised two factors viz. variety (3)- (BRRI dhan48, BRRI dhan98, and Binadhan-21) and five different levels of sorghum crop residue extract with recommended doses of herbicide and in second year experiment the varieties and treatments were the same except mustard crop residues. Principal component analysis of weed dry matter revealed that several treatment combinations were effective against *Panicum repens, Cyperus rotundus*, *Echinochloa crus-galli*, and *Ludwigia octovalvis*. The radar graph revealed that the highest percentage of weed inhibition was 80.96% against *Cyperus difformis* using a treatment of 80% RDH with boiled sorghum residue extract compare than mustard residue extract at post-emergence. The maximum Number of grain panicles^{-1}(105.59), grain yield (5.36 t ha^{-1}), Biological yield (11.63 t ha^{-1}) and Harvest index (46.04%) was overserved by combining BRRI dhan98 and the 80% RDH with boiled sorghum residue extract. In the case of Mustard boiled crop residues extract, the highest Number of grain panicles^{-1}(105.52), grain yield (5.28 t ha^{-1}), Biological yield (11.61 t ha^{-1}) and Harvest index (45.45%) was overserved by combining BRRI dhan98 and the 80% RDH with boiled mustard residue extract. The study concluded that reduced herbicide doses integrated with boiled sorghum and mustard crop residue extract effectively suppressed weeds and increased the yield of transplanted *aus* rice.

Keywords: Weed inhibition; percent inhibition; principal component analysis; grain; allelopathy; integrated weed management.

1. Introduction

Rice (*Oryza sativa* L.) is the main source of nutrition for over 150 million people living in Bangladesh. According to **(Anon, 2018)**, it contributes to around 48% of employment in rural areas, supplies over two-thirds of the total calories consumed, and accounts for almost 50% of the overall protein consumption for an average individual in the country. Consequently, the country presently yields a remarkable 38.14 million tons of rice over an expanse of 11.70 million hectares of land to meet the dietary requirements of its extensive population **(BBS, 2022).** The total area under the Transplant (T.) *aus* rice has been estimated at 10,61,273 hectares, and the average yield rate of T. *aus* rice has been estimated at 2.734 metric tons of husked rice hectare^{-1} in the years 2022–2023 **(BBS, 2023).** Due to low-yielding varieties, heavy weed infestations, and inadequate crop management, the average rice production is declining. Weed infestation is the most prominent problem causing poor aus rice output among these issues. Weeds are among the most critical constraints on crop production worldwide, including in Bangladesh. Crop production is frequently compared to the fight against weeds **(Kumar and Goh, 2000).** Weed severe tendencies

*Corresponding author email: romijagron@bau.edu.bd Orcid ID: 0000-0003-2188-7619
Received: 03/06/2025; Accepted: 10/09/2025
DOI: 10.21608/agro.2025.391870.1716
©2025 National Information and Documentation Center (NIDOC)

to compete with crop yields have detrimental consequences for production, leading to notable reductions in agriculture output. Approximately 11.5% of the global production of essential crops is lost because of weed infestation, according to estimates. Growing seasons and agroecological factors always affect weed infestation in rice fields **(BRRI, 2017).** Without weed control, rice production can be decreased by 16 to 88% or even 100%. As a result, weed infestation lowers transplanted rice variety grain production by 70–80% (early summer), 30-40% for T. *aman* rice (late summer) and 22-36% for modern boro rice varieties (winter rice) **(BRRI, 2018).** The massive loss in yield presupposes that weeds are seriously detrimental to crop production and need to be either prevented from growing or eliminated. It is a severe limitation of crop production for an overpopulated small country such as Bangladesh. Proper weed management is important for rice yield in Bangladesh. Many kinds of weeds prevail in a rice field. Generally, they are categorized under three groups based on their morphological appearance, i.e., grasses, sedges, and broadleaf weeds. In our country, the traditional methods of weed control, such as preparatory land tillage, hand weeding with hoe and hand pulling are quite common. The former, among the practice of hand weeding, is in vogue in the country **(Dola *et al.*, 2024).** Normally, two or three hand weeding are given for raising a crop of rice depending upon the nature of weeds, their degree of infestation and crop grown. But adverse weather conditions or lack of labor may constrain weed control at critical periods by the traditional method. It was also observed that it was not enough to get satisfactory weed control even though both pre- and post-emergence herbicides were applied in direct-seeded rice **(Chauhan *et al.*, 2015).**

In transplanted rice, chemical weed management by utilizing selective herbicides as pre-emergence and post-emergence herbicides is also a widespread technique together with other approaches **(Mitra *et al.*, 2022).** For example, Bispyribac-sodium, a post-emergence herbicide successfully controls grassy weeds as well as contributing the greatest yield components, yield and economics of transplanted rice field **(Biswas *et al.*, 2020; Safina *et al.*, 2017).** However, numerous chemical substances have been developed in recent years and used as herbicides globally to manage weed population efficiently, but unconscious and the reckless use of these chemicals has exerted negative consequences on crop plants' phenology, physiological and biochemical attributes, leading to phytotoxicity and decreased yields **(Blackshaw, 2005).**

Researchers suggested the use of various crop residues for weed control as a means of controlling weed infestations. The crops or their different parts left on the field for deterioration following threshing or harvesting is called crop residues **(Kumar and Goh, 2000).** Weeds cannot grow when crop allelopathy breaks down phytotoxic plant residues and releases allelochemicals from living plants **(Belz, 2004; Khanh, 2005).** It is generally known that many plants, including all major grain crops, like rice, rye, barley, sorghum, wheat, and others, may limit the growth of some weeds and produce phytotoxic symptoms **(Belz, 2004).** Although they were often thought of as nothing more than garbage, due to their efficacy, they are now seen as a valuable resource that, when broken down, may significantly alter the qualities of the soil. Furthermore, several studies have found that plants and plant residues can exert allelopathic effects on numerous crops such as major cereal crops (wheat, rye), mustard, rice, buckwheat, sorghum, other crop residues **(Uddin and Pyon, 2010; Uddin *et al.*, 2010; Won *et al.*, 2013; Ferdousi *et al.*, 2017; Hossain *et al.*, 2017; Sheikh *et al.*, 2017; Ahmed *et al.*, 2018; Pramanik *et al.*, 2019; Sarker *et al.*, 2020; Zeidali *et al.*, 2025).** Although the general use of crop residues for weed management has been addressed in prior works, this study attempts the gaps by testing the weed suppressive capacity of boiled allelopathic extracts of sorghum and mustard in combination with lower doses of herbicides in transplanted *aus* rice.

There is some research that has already been done to control weeds with the use of crop residues. **Sarker *et al.* (2022)** found that using a combination of BARI Gom-31 and 90% of the recommended herbicide dose with aqueous extraction of grass pea resulted in the highest crop yields and effective weed control. This indicates that grass pea residue extract could be a promising sustainable option for managing weeds in crop production. **Ashraf *et al.* (2021)** demonstrated that hand weeding followed by combined application of grass pea and mustard crop residues 1 t ha^{-1} of each showed potential activity to suppress weed growth. **Rahman *et al.* (2020)** examined that the highest percent inhibition of 58.31%, 46.84%, 66.85%, 66.94% and 57.6% was in Panikachu (*Monochoria vaginalis*), Shama *(Echinochloa crusgalli*), Chesra (*Scirpus juncoides*), Sabujnakful (*Cyperus difformis*) and Amrul (*Oxalis corniculata*), respectively caused by sorghum crop residues and BR11 under sorghum crop residues @ 2.0 t ha^{-1} produced the highest grain (5.76 t ha^{-1}) and straw yield (6.39 t ha^{-1}). **Sarker *et al.* (2020)** found that the highest percent weed inhibition was found in sunflower crop residues at 2 t ha^{-1} treatment which was 47.29, 52.03, 51.28, 71.41 and 70.44 percent for Shama (*Echinochloa crusgalli*), Amrul (*Oxalis corniculata* L.), Panikachu (*Monochoria vaginalis*), Sabujnakful (*Cyperus difformis*) and Chesra

(*Scirpus juncoides*), respectively and Binadhan-16 produced the highest grain and straw yields with sunflower residues 2.0 t ha^{-1} treatment.

One of the most significant allelopathic crops is sorghum (*Sorghum bicolor* L.), often employed as a cover crop or by integrating its residue into the soil to suppress weeds. Experimental studies have shown that sorghum is an effective weed rival in fields. Sorghum inhibits the growth of some weeds. These point to sorghum allelopathic ability, which benefits the biological control of weeds. Also, mustard is a successful competitor against weeds in fields as empirically known **(Hossain *et al.*, 2017).** Weed control using boiled sorghum and mustard crop residue extract in T. *aus* is rare. So, the study aimed to examine the weed-controlling ability of a boiling extract derived from sorghum and mustard crop residue and determine the optimum amount to use for effective weed control and improved rice yield. This research is necessary both locally and globally due to the residual effects of boiled extract on crop yield performance and weed control **(Ahmed *et al.*, 2018).**

Sorghum (*Sorghum bicolor*) and mustard (*Brassica* spp. have been described as two of the most potential allelopathic plants species used as cover or residue incorporation crops for weed control. Crop residues were previously considered as agricultural waste, but now they are considered as valuable inputs, the allelopathic properties of which have been widely documented and can be an important strategy for weed management when applied into arable soils. It has been proved that sorghum and mustard have very strong weed suppressive potential because of their good early growth. These characteristics exhibit allelopathic potential of sorghum and mustard and in favor of their use as a biological method of weed management. In view of these considerations, the experiment was carried out to investigate the impact of boiled extract of sorghum and mustard crop residues on different parameters of weed suppression and transplanted aus rice (*Oryza sativa* L.) yield.

2. Materials and Methods:

2.1 Description of the experimental site

The experiment was conducted at the Agronomy Field Laboratory (AFL) of Bangladesh Agricultural University (BAU), Mymensingh during aus rice growing season (May to September) of 2022 and 2023 in Bangladesh. In terms of location, the study was located at longitude 90°50′ E, latitude 24°25′ N, and elevation 18 m above sea level. The test location was in the Old Brahmaputra floodplain (AEZ-9) **(FAO and UNDP, 1988).** The climate in this area is classified as a subtropical monsoon and characterized by substantial precipitation from April to October and less precipitation from October to March. Prior to the initiation of the experiment, composite topsoil samples (0–15 cm depth) were systematically collected from the entire experimental field following a zigzag sampling pattern to ensure representativeness. At each sampling point, approximately 500 grams of soil were extracted using a stainless-steel auger. The collected samples were then thoroughly composited in a clean plastic container to form a uniform bulk sample. From this bulk, subsamples were taken, air-dried under shade, gently ground, and sieved through a 2 mm mesh and the analyzed morphological, chemical and physical features of the soil are detailed in **(Table 1-3)**.

Table 1. The morphological properties of the experimental field.

Constituents	Characteristics
Location	Agronomy Field Laboratory, BAU
Soil Series	Sonatola
Soil Tract	Old Brahmaputra Alluvium
Land type	Medium High Land
General soil type	Non-calcareous dark grey floodplain
Agro-ecological zone	Old Brahmaputra Floodplain (AEZ-9)
Topography	Fairly level
Soil type and colour	Dark grey Terrace Soil
Drainage	Moderate
Depth of inundation	Above the flood level
Drainage condition	Well drained

Table 2. The physical properties of the experimental field.

Constituents	Results
Particle size analysis	2.57
Bulk density (g/ce)	1.42
Porosity (%)	44.7
Sand (%) (0.0-0.02mm)	21.75
Silt (1%) (0.02-0.002mm)	66.60
Clay (%) (<0.002mm)	11.65
Soil textural class	Silt loam
Colour	Dark grey
Consistency	Grounder

Table 3. The chemical properties of the experimental field
Chemical composition of the initial soil (0-15 cm depth).

Constituents	Results
Soil pH	6.8
Organic matter (%)	1.30
Total nitrogen (%)	0.101
Available phosphorus (ppm)	27
Exchangeable potassium (me%)	0.12
Available Sulphur (ppm)	22.7

2.2 Experimental treatments

Two components were used in the experimental treatment: three rice varieties, viz. BRRI dhan48, BRRI dhan98, and Binadhan-21 were transplanted and subjected to the application of five different doses of boiled extracts of sorghum along with a reduced rate of herbicide, viz., no weeding (control), the recommended dose of herbicide (RDH) at post-emergence, 80% of the (RDH) at post-emergence with boiled sorghum crop extracts, 70% of the (RDH) at post-emergence with boiled sorghum crop extracts and 60% of the (RDH) at post-emergence with boiled sorghum crop extracts and same as another experiment subjected to the application of five different doses of boiled extracts of mustard along with reduced rate of herbicide, viz., no weeding (control), the recommended dose of herbicide (RDH) at post-emergence, 80% of the (RDH) at post-emergence with boiled mustard crop extracts, 70% of the (RDH) at post-emergence with boiled mustard crop extracts and 60% of the (RDH) at post-emergence with boiled mustard crop extracts. The experiment was conducted with a RCBD, arranged in a factorial way using three replications. The measurements of the plots were 4.0 m × 2.5 m, with a spacing of 25 cm between rows and 15 cm between hills. The total number of experimental plots was 45 plots (3 varieties × 5 treatments × 3 replications).

2.3 Collection and preparation of experimental materials

In this study, boiled extracts of sorghum and mustard crop residues were used. Crops were produced at the AFL of BAU and collected at the ripening stage. After collecting, the crop residues were dried in a shaded area on the covered threshing floor of the AFL, BAU. The crop residues were finely minced with a sickle. The sorghum and mustard crop residues of smaller size were immersed in water at a ratio of 1:5 (weight/volume), meaning 1 part (e.g., 100 grams) of crop residue was immersed in 5 parts (e.g., 500 milliliters) of water for 24 hours at the current room temperature. The combination of leaves and water was boiled for 4 hours at 100^0c temperature. Subsequently, the resulting water extract was filtered using a coarse mesh to eliminate any remnants of the plant material. The seed of Binadhan-21 was collected from Bangladesh Institute of Nuclear Agriculture and that of BRRI dhan48 and BRRI dhan98 were collected from Bangladesh Rice Research Institute. After collecting the seeds, the specific gravity technique was used to pick healthy seeds from the collected varieties. The seeds were subsequently submerged in water in a container for 24 hours. Afterwards, the seeds were removed from the water and tightly packed in gunny bags. The germination begins after 48 hours, and the seed becomes prepared for sowing.

2.4 Preparation of plots and Crop husbandry

A plot of land was chosen for the purpose of cultivating seedlings. The soil underwent deep ploughing with a tractor and then levelling with a ladder. The implanted seedlings were placed evenly in the nursery bed that had been prepared for them on May 10, 2022, and next year on May 7, 2023. On June 6, 2022, and June 2, 2023, the field was prepared with a tractor which drew a plough. After the ploughing, the ladder was used to properly prepare the field for cultivation. The fields design was established after the completion of the final stage of land preparation. The individual plots are free of any weeds or stubbles. The experimental plots for BRRI dhan48 and BRRI dhan98 were fertilized with urea, triple super phosphate (TSP), muriate of potash (MoP), gypsum and zinc sulphate all at the rate of 80, 28, 40, 20 ,2.8 kg ha^{-1}, respectively **(BRRI, 2020)**. The entire amounts of MoP, TSP, zinc sulphate, gypsum and $1/3^{rd}$ of urea were applied at the time of final land preparation. The rest of the urea was applied in two installments in equal splits at 15 and 30 days after transplanting (DAT). On the other hand, for Binadhan-21 variety the experimental plots were fertilized with urea, TSP, MoP, gypsum and zinc sulphate @ 160, 75, 60, 65, 5.56 kg ha^{-1}, respectively **(BINA, 2022).** The entire amounts of TSP, MoP, gypsum, zinc sulphate were applied at the time of final land preparation. Urea was applied in two installments in equal splits at 10 and 35 DAT. The hoeing and weeding operation of the plot was done with power sprayer dose. Seedlings from both varieties were then transplanted on June 9, 2022, and June 5, 2023. After transplanting seedlings in the plots, five different doses of boiling extracts of sorghum crop residues along with reduced amount of herbicide were applied in the plots according to the specific treatment. Various intercultural practices, including gap filling, weeding, irrigation and drainage were performed as necessary.

2.5 Application of boiled extract of sorghum and mustard along with reduced rate of herbicide

The prepared boiled sorghum and mustard crop residue extracts along with reduced rate of herbicide were applied on 22 June 2022 and June 20, 2023, as RDH at post emergence (T_2), 80% of RDH at post emergence + boiled crop extracts (T_3), 70% of RDH at post emergence + boiled crop extracts (T_4) and 60% of RDH at post emergence + boiled crop extracts (T_5). The spray volume of boiled extracts along with reduced rate of herbicide was 500L ha^{-1}.

2.6 Harvesting and data collection

Data on weed population (30 DAT) were collected from each plot of the rice plants using 0.25 m × 0.25 m) quadrate as per the method described by **(Cruz *et al.*, 1986)**. The weeds within the quadrate were counted and converted to number m^{-2}, multiplied by four. After measuring the weed density, the weeds inside each quadrate were uprooted, cleaned, separated species-wise. After that the weed samples dried in the sun and placed in an electric oven for 72 hours at a temperature of 80^{0}c. The dry weight (DW) of each species was taken by an electric balance and expressed in gm^{-2}. Percent inhibition (PI) of weed was calculated using the following formula:

$$\% \text{ Inhibition} = \frac{\text{DW of weed at control} - \text{DW of weed from treatment}}{\text{DW of weed at control}} \times 100$$

The harvesting process was carried out on August 29, 2022, and on August 26, 2023, when the crops reached the appropriate level of maturity for harvesting and 1 m^2 area was chosen in the central section of each plot to measure the GY and SY. The grain yield (GY) was converted to a moisture content of 14% and translated to metric tons hectare^{-1}. No. of total tiller hill^{-1} (NTT), and total DW hill^{-1} were recorded for each plot, with five hills being tagged. The data was collected 30 DAT. During harvest, plant height (PH), number of effective tillers hill^{-1} (NET), panicle length (PL), number of grains panicle^{-1} (NG), 1000-grain weight (TGW), grain yield (GY), and straw yield (SY) were all measured. Furthermore, the biological yield (BY) and harvest index (HI) were also computed. Biological yield of rice was calculated by using the following formula:

Biological yield =Economic Yield + Non-economic Yield

Here, Economic yield = grains yield; non-economic yield = straw yield

The harvest index of rice was determined using the following formula:

$$\text{Harvest index} = \frac{\text{Grain yield}}{\text{Biological yield}} \times 100$$

2.7 Statistical analysis

The statistical program R-studio was utilized to do the analysis of variance, whereas Duncan's Multiple Range Test **(Gomez and Gomez, 1984).** Data was compiled and tabulated in proper form for statistical analysis which was carried out in statistical software R version 3.4.1. Data management and graph preparation were done using MS Office Excel®. Various statistical tests such as the two-factor ANOVA test, mean performance, Radar graph, and PCA analyses were performed through opensource statistical platform 'R' (R Core Team, 2022).

3. Results and Discussion

3.1 Infested weed species in the two experimental fields

The experimental plots were invaded by six weed species from five different families. (Table 4) provides the local name (LN), scientific name (SN), family, morphological type (MT), and life cycle (LC) of the weed observed in the experimental plots. The weeds of the experimental plots were *Cyperus rotundus, Echinochloa crus-galli***,** *Panicum repens, Cyperus difformis,* and *Ludwigia octovalvis.* Among the weed species one was broadleaf, two sedges and two grasses type morphology. There were two annual and three perennial weed species in the experimental plot.

Table 4. Infested weed species found growing in the two experimental plots in rice;

Sl. No.	LN	SN	Family	MT	LC
1.	Mutha	*Cyperus rotundus*	Cyperaceae	Sedge	Perennial
2.	Shama	*Echinochloa crus-galli*	Poaceae	Grass	Annual
3.	Angta	*Panicum repens*	Poaceae	Grass	Perennial
4.	Sabuj nakful	*Cyperus difformis*	Cyperaceae	Sedge	Annual
5.	Pani long	*Ludwigia octovalvis*	Onagraceae	Broadleaf	Perennial

3.2 Comparison between the interaction effect of variety and reduced rate of herbicides along with boiled extract of crop residues on weeds population

The interaction between rice variety, boiled crop residue extracts (sorghum and mustard), and reduced herbicide doses significantly influenced weed populations (WP) (Table 5). Under boiled sorghum extract treatments, the highest WP of *Cyperus rotundus* (13.00) was recorded in Binadhan-21 under control conditions, while the lowest (3.33) was observed in BRRI dhan48 with 80% RDH plus boiled extract. *Echinochloa crus-galli* WP was highest in BRRI dhan98 with no weeding (9.33), and consistently lower across all varieties when treated with boiled extracts and herbicide. *Panicum repens* were most reduced in Binadhan-21 with 60% RDH plus boiled extract (14.33). Sabuj nakful WP peaked in BRRI dhan48 (39.00) and BRRI dhan98 (40.33) under no weeding, while the lowest count (7.67) was found in BRRI dhan98 with 80% RDH and boiled extract. Pani long was most abundant in BRRI dhan48 (12.67) and BRRI dhan98 (11.67) under no weeding, and least in BRRI dhan48 and Binadhan-21 (2.33 each) with 80% RDH plus boiled extract. Similarly, under boiled mustard extract treatments, the highest WP of *C. rotundus* (13.00) occurred in Binadhan-21 without weeding, and the lowest (3.33) in BRRI dhan98 with 80% RDH and boiled extract. *E. crus-galli* reached a maximum of 9.00 in Binadhan-21 with no weeding and declined across all varieties with herbicide and extract. P. repens WP was highest in Binadhan-21 (17.33) with no weeding and lowest (3.67) in BRRI dhan98 with 80% RDH plus boiled extract. Sabuj nakful WP was highest in BRRI dhan48 (36.67) and Binadhan-21 (38.00), and lowest (6.67) in BRRI dhan98 with 80% RDH plus boiled extract. Pani long counts were highest in BRRI dhan48 (11.50), BRRI dhan98 (11.33), and Binadhan-21 (11.67) with no weeding, and lowest in BRRI dhan98 (2.67), BRRI dhan48 (3.33), and Binadhan-21 (3.50) with 80% RDH and boiled extract.

Overall, both boiled sorghum and mustard extracts in combination with reduced herbicide rates significantly suppressed weed populations across all species. Mustard extract with 80% RDH showed slightly superior efficacy in weed suppression compared to sorghum extract. The integrated approach using various doses of herbicide combined with boiled crop residue extract, known as integrated weed management, effectively controlled weeds compared to using only herbicides. Among the five treatments tested which included 80% of RDH dose along with boiled sorghum crop extract, yielded the best results. Weed inhibition percentages ranged from 77.52% to 16.22% across treatments. Neither herbicides alone nor crop residue extracts alone demonstrated superior weed suppression, but their combination showed better performance (**Sarker *et al.*, 2022**). The findings of many studies showed that applying crop residues extracts to enhance the weed suppression and production of yield. Crop residues generally suppressed weeds effectively. Among the cultivars, BR11 produced the highest yields. The most effective treatments for suppressing weeds were hand weeding and the combined residue application, with hand weeding in combination with BR11 yielding the highest grain (4.81 t/ha) and straw (7.65 t/ha) outputs (**Ashraf *et al.*, 2021**).

Table 5. Interaction effect of variety and reduced rate of herbicides along with boiled extracts of crop residues on number of weeds.

Number of weeds										
Boiled extracts of sorghum						**Boiled extract of mustard**				
Interaction	**Mutha (*C. rotundus*)**	**Shama (*E. crus-galli*)**	**Angta (*P. repens*)**	**Sabuj nakful (*C. difformis*)**	**Pani long (*L. octovalvis*)**	**Mutha (*C. rotundus*)**	**Shama (*E. crus-galli*)**	**Angta (*P. repens*)**	**Sabuj nakful (*C. difformis*)**	**Pani long (*L. octovalvis*)**
V_1T_1	11.00b	6.33b-d	10.33de	39.00a	11.67ab	11.67ab	8.67a	10.67d	36.67a	11.50a
V_1T_2	4.67fg	3.33fg	6.00i	17.33f	4.33fg	5.67ef	4.33e	5.33g	17.33f	5.00d
V_1T_3	3.33g	2.67g	4.67j	11.67h	2.33h	4.33fg	3.67e	5.00g	10.67h	3.33e
V_1T_4	7.00de	4.33ef	7.67gh	21.33e	5.00f	8,00cd	6.67bc	7.33f	22.00e	5.33d
V_1T_5	8.33cd	5.33de	8.67fg	28.67cd	7.33cd	9.33c	6.83b	8.33ef	31.00c	7.33c
V_2T_1	11.67ab	9.33a	11.00cd	40.33a	12.67a	11.00b	6.67bc	10.33d	32.67b	11.33a
V_2T_2	7.33d	4.67e	7.67gh	11.67h	5.00f	4.67fg	3.67e	5.33g	10.67h	4.67d
V_2T_3	5.33f	3.33fg	4.33j	7.67i	3.33gh	3.33g	2.33f	3.67h	6.67i	2.67e
V_2T_4	7.67d	6.33b-d	8.67ef	21.67e	6.33de	7.00de	4.67de	7.33f	24.00d	4.83d
V_2T_5	9.33c	7.00bc	9.67ef	30.00c	8.33c	8.33cd	5.67cd	9.00e	31.00c	6.83c
V_3T_1	13.00a	9.00a	18.00a	37.00b	11.00b	13.00a	9.00a	17.33a	38.00a	11.67a
V_3T_2	5.67ef	4.67e	11.00cd	15.00g	5.33ef	7.67d	4.50e	11.33cd	13.33g	5.67d
V_3T_3	4.33fg	3.33fg	7.33h	11.67h	2.33h	5.00f	3.67e	8.67e	10.33h	3.50e
V_3T_4	8.00cd	6.00cd	12.00c	21.67e	6.67d	8.00cd	6.83b	12.33c	23.67d	6.83c
V_3T_5	9.33c	7.33b	14.33b	27.33d	8.33c	9.33c	7.00b	15.33b	32.67b	8.67b
Level of sig.	*	*	**	**	*	*	*	**	**	*
CV (%)	10.71	12.78	7.60	8.16	10.45	11.35	10.91	7.17	5.21	9.23

Here, means with the same letters within the same column do not differ significantly as per DMRT. * - Significant at 5% level of probability, here, **- Significant at 1% level of probability, V_1- BRRI dhan48, V_2 - BRRI dhan98, V_3 - Binadhan-21, T_1 - no weeding (control), T_2 - RDH at post emergence, T_3 - 80% of RDH at post emergence + boiled crop extracts, T_4-70% of RDH at post emergence + boiled crop extract, T_5 -60% of RDH at post emergence + boiled crop extracts.

3.3 Comparison between the interaction effect of variety and reduced rate of herbicides along with boiled extract of crop residues on dry weight of weeds

The interaction between rice variety, boiled crop residue extracts (sorghum and mustard), and reduced herbicide doses significantly influenced the dry weight (DW) of weeds (Table 6). In case of boiled extract of sorghum treatments, the highest DW of *Cyperus rotundus* (5.98 g m^{-2}) was observed in Binadhan-21 under no weeding, while the lowest (1.53 g m^{-2}) occurred in BRRI dhan48 with 80% recommended dose of herbicide (RDH) + boiled extract. For *Echinochloa crus-galli*, the maximum DW (8.54 g m^{-2}) was recorded in BRRI dhan98 under no weeding, and the minimum (2.45 g m^{-2}) in BRRI dhan48 with 80% RDH + boiled extract. *Panicum repens* showed the most notable reduction in Binadhan-21 with 60% RDH + boiled extract (12.40 g m^{-2}). The highest DW of Sabuj nakful was recorded in BRRI dhan48 (12.83 g m^{-2}) and BRRI dhan98 (13.27 g m^{-2}) under no weeding, while the lowest (2.52 g m^{-2}) was observed in BRRI dhan98 with 80% RDH + boiled extract. For Pani long, the maximum DW was in BRRI dhan48 (2.45 g m^{-2}) and BRRI dhan98 (2.66 g m^{-2}) under no weeding, and the minimum (0.49 g m^{-2}) in BRRI dhan98 with 80% RDH + boiled extract. Under boiled mustard extract treatments, the highest DW of *C. rotundus* (6.83 g m^{-2}) was observed in Binadhan-21 with no weeding, while the lowest was in BRRI dhan98 (3.17 g m^{-2}) and BRRI dhan48 (3.37 g m^{-2}) with 80% RDH + boiled extract. For *E. crus-galli*, the maximum DW occurred in Binadhan-21 (9.00 g m^{-2}) and BRRI dhan48 (8.67 g m^{-2}) under no weeding, and the minimum (2.33 g m^{-2}) in BRRI dhan98 with 80% RDH + boiled extract. *P. repens* had the highest DW in Binadhan-21 with no weeding (10.50 g m^{-2}) and the lowest (5.00 g m^{-2}) in BRRI dhan98 with 80% RDH + boiled extract. For Sabuj nakful, the maximum DW (11.50 g m^{-2}) was noted in Binadhan-21 under no weeding, and the minimum (2.67 g m^{-2}) in BRRI dhan98 with 80% RDH + boiled extract. The DW of Pani long peaked in BRRI dhan48 (2.83 g m^{-2}), BRRI dhan98 (2.81 g m^{-2}), and Binadhan-21 (3.00 g m^{-2}) under no weeding, while the lowest DW (0.67 g m^{-2}) was recorded in BRRI dhan98 with 80% RDH + boiled extract. The above results illustrated that sorghum, and mustard extracts can reduce weed biomass with reduced herbicide rates. Sorghum extract demonstrated slightly superior broad-spectrum weed control efficacy, indicated by lower DW measurements across more weed types compared to mustard extract treatments. The study examined the effects of wheat crop residues on weed control and crop yield in plots infested by five weed species from three families. Without crop residues, weed growth was at its maximum, while the incorporation of 2.0 t/ha of wheat residues minimized weed growth. This treatment also achieved the highest weed inhibition, with rates up to 82.24%. Among the tested cultivars, BRRI dhan49 yielded the highest grain output. Overall, applying 2.0 t/ha of wheat crop residues significantly reduced weed presence and enhanced crop performance, including the number of tillers per hill, grains per panicle, 1000-grain weight, grain yield, and straw yield **(Ferdousi *et al.*, 2017; Absy *et al.*, 2022; Mostofa *et al.*, 2024)**.

Table 6. Interaction effect of variety and boiled extract of crop residue and herbicide on dry weight of weeds.

DW (g m^{-2}) of weeds										
	Boiled extracts of sorghum					**Boiled extract of mustard**				
Interaction	**Mutha (*C. rotundus*)**	**Shama (*E. crus-galli*)**	**Angta (*P. repens*)**	**Sabuj nakful (*C. difformis*)**	**Pani long (*L. octovalvis*)**	**Mutha (*C. rotundus*)**	**Shama (*E. crus-galli*)**	**Angta (*P. repens*)**	**Sabuj nakful (*C. difformis*)**	**Pani long (*L. octovalvis*)**
V_1T_1	5.06b	5.95bc	8.94de	12.83a	2.45ab	5.37bc	8.67a	9.67ab	10.83ab	2.83a
V_1T_2	2.15fg	3.06ef	5.19i	5.70f	0.91fg	3.50ef	4.33e	6.17hi	4.50ef	1.27d-h
V_1T_3	1.53g	2.45f	4.04j	3.84h	0.49h	3.37f	3.67e	5.67ij	3.83ef	0.83gh
V_1T_4	3.22de	3.97de	6.63gh	7.02e	1.05f	3.53ef	6.67bc	7.83ef	8.00cd	1.67c-e
V_1T_5	3.83cd	4.88cd	7.50fg	9.43cd	1.54cd	4.29d	6.83b	8.50c-e	8.83c	2.17bc
V_2T_1	5.37ab	8.54a	9.52cd	13.27a	2.66a	5.34bc	6.67bc	9.33bc	10.67ab	2.81a
V_2T_2	3.37d	4.27d	6.63gh	3.84h	1.05f	3.33f	3.67e	5.83ij	3.67fg	1.12e-h
V_2T_3	2.45f	3.05ef	3.75j	2.52i	0.70gh	3.17f	2.33f	5.00j	2.67g	0.67h
V_2T_4	3.53d	5.80bc	7.50fg	7.13e	1.33de	3.50ef	4.67de	7.5fg	7.17d	1.5d-f
V_2T_5	4.29c	6.41b	8.26ef	9.87c	1.75c	4.23de	5.67cd	8.17d-f	8.00cd	1.83cd
V_3T_1	5.98a	8.24a	15.57a	12.18b	2.31b	6.83a	9.00a	10.50a	11.50a	3.00a
V_3T_2	2.61ef	4.27d	9.52cd	4.94g	1.12ef	4.67cd	4.50e	6.83gh	4.83e	1.33d-g
V_3T_3	1.99fg	3.05ef	6.35h	3.84h	0.49h	4.35d	3.67e	6.17hi	4.17ef	1.00f-h
V_3T_4	3.68cd	5.49bc	10.38c	7.13e	1.40d	4.83cd	6.83b	8.83b-d	8.67c	2.17bc
V_3T_5	4.29c	6.61b	12.40b	9.00d	1.75c	5.67b	7.00b	9.50b	10.00b	2.50ab
Level of sig.	*	*	**	**	*	*	*	**	*	*
CV (%)	10.70	12.50	7.55	8,15	10.44	9.91	10.91	7.13	8.42	11.14

Here, means with the same letters within the same column do not differ significantly as per DMRT. * - Significant at 5% level of probability, here, **- Significant at 1% level of probability, V_1- BRRI dhan48, V_2 - BRRI dhan98, V_3 - Binadhan-21, T_1 - no weeding (control), T_2 - RDH at post emergence, T_3 - 80% of RDH at post emergence + boiled crop extracts, T_4-70% of RDH at post emergence + boiled crop extract, T_5 -60% of RDH at post emergence + boiled crop extracts.

3.4 Principal Component Analysis (PCA) of weed dry matter (WDM)

Principal component analysis (PCA) was performed employing the trial dataset comprising five weed flora and 29 distinct factors to minimize the heterogeneity of the data and find probable associations between weed species and measured features (Figure 1). The PCA found that the first two principal components (PCs) with Eigen scores greater than one described 93.9% of the overall heterogeneity. Because the first and second PCs generated 87% and 6.9% of the entire divergence, correspondingly, a PCA biplot was constructed with only the first one component. The PCA biplot revealed that the dry matter of *Panicum repens* is favored by using sorghum extract and interaction between BRRI dhan48 in combination with 80% RDH, BRRI dhan98 in combination with RDH, BRRI dhan98 in combination with 70% RDH, BRRI dhan48 in combination with 70% RDH, Binadhan-21 in combination with 80% RDH, Binadhan-21 in combination with RDH, Binadhan-21 in combination with 70% RDH, Binadhan-21 in combination with 60% RDH and by using mustard extract and interaction between BRRI dhan98 in combination with 70% RDH treatments. In other words, these treatments are not effective for controlling *Panicum repens*. On the other hand, weeds of *Cyperus rotundus, Echinochloa crus-galli and Ludwigia octovalvis* are associated with PC1. Higher dry matter of these weeds was produced by using sorghum extract and interaction between BRRI dhan48 in combination with 60% RDH, BRRI dhan98 in combination with 60% RDH, BRRI dhan98 in combination with no weeding (control) and by using mustard extract and interaction between BRRI dhan98 in combination with 60% RDH, Binadhan-21 in combination with 70% RDH, BRRI dhan48 in combination with 60% RDH, Binadhan-21 in combination with 60% RDH, BRRI dhan98 in combination with no weeding, BRRI dhan48 in combination with no weeding, Binadhan-21 in combination with no weeding treatments. Therefore, these treatments are not effective against *Cyperus rotundus, Echinochloa crus-galli* and *Ludwigia octovalvis* weeds. Among the interaction treatments, by using sorghum extract and BRRI dhan48 in combination with RDH, BRRI dhan98 in combination with 80% RDH along with boiled extracts of sorghum and by using mustard extract and BRRI dhan98 in combination with RDH, BRRI dhan48 in combination with 80% RDH along with boiled extracts of mustard, BRRI dhan48 in combination with RDH, BRRI dhan48 in combination with RDH, Binadhan-21 in combination with 80% RDH along with boiled extracts of mustard, Binadhan-21 in combination with RDH were effective against weeds of *Panicum repens, Cyperus rotundus, Echinochloa crus-galli* and *Ludwigia octovalvis*. The response of *Cyperus difformis* could be explained with neither PC1 nor PC2. The PCA analysis revealed associations between weed species and treatments. Treatments like by using sorghum extract and interaction between BRRI dhan48 in combination with 80% RDH, BRRI dhan98 in combination with RDH, BRRI dhan98 in combination with 70% RDH, BRRI dhan48 in combination with 70% RDH, Binadhan-21 in combination with 80% RDH, Binadhan-21 in combination with RDH, Binadhan-21 in combination with 70% RDH, Binadhan-21 in combination with 60% RDH and by using mustard extract and interaction between BRRI dhan98 in combination with 70% RDH treatments were not effective against *Panicum repens*, while by using sorghum extract and interaction between BRRI dhan48 in combination with 60% RDH, BRRI dhan98 in combination with 60% RDH, BRRI dhan98 in combination with no weeding (control) and by using mustard extract and interaction between BRRI dhan98 in combination with 60% RDH, Binadhan-21 in combination with 70% RDH, BRRI dhan48 in combination with 60% RDH, Binadhan-21 in combination with 60% RDH, BRRI dhan98 in combination with no weeding, BRRI dhan48 in combination with no weeding, Binadhan-21 in combination with no weeding treatments are favoured against *Cyperus rotundus, Echinochloa crus-galli, and Ludwigia octovalvis*. Certain interaction treatments by using sorghum extract and BRRI dhan48 in combination with RDH, BRRI dhan98 in combination with 80% RDH along with boiled extracts of sorghum and by using mustard extract and BRRI dhan98 in combination with RDH, BRRI dhan48 in combination with 80% RDH along with boiled extracts of mustard, BRRI dhan48 in combination with RDH, BRRI dhan48 in combination with RDH, Binadhan-21 in combination with 80% RDH along with boiled extracts of mustard, Binadhan-21 in combination with RDH were effective against multiple weed species. However, the response of *Cyperus difformis* remained unexplained by PC1 or PC2, necessitating further investigation. **Loureiro *et al.* (2019)** highlighted glyphosate's role in integrated weed management in PCA analysis, **Chipomho *et al.* (2021)** discussed in PCA analysis the influence of soil organic carbon and weeding regimes on weed dynamics, and **Dentika *et al.* (2021)** explored weeds as pathogen hosts and disease risk factors in the context of reduced herbicide use.

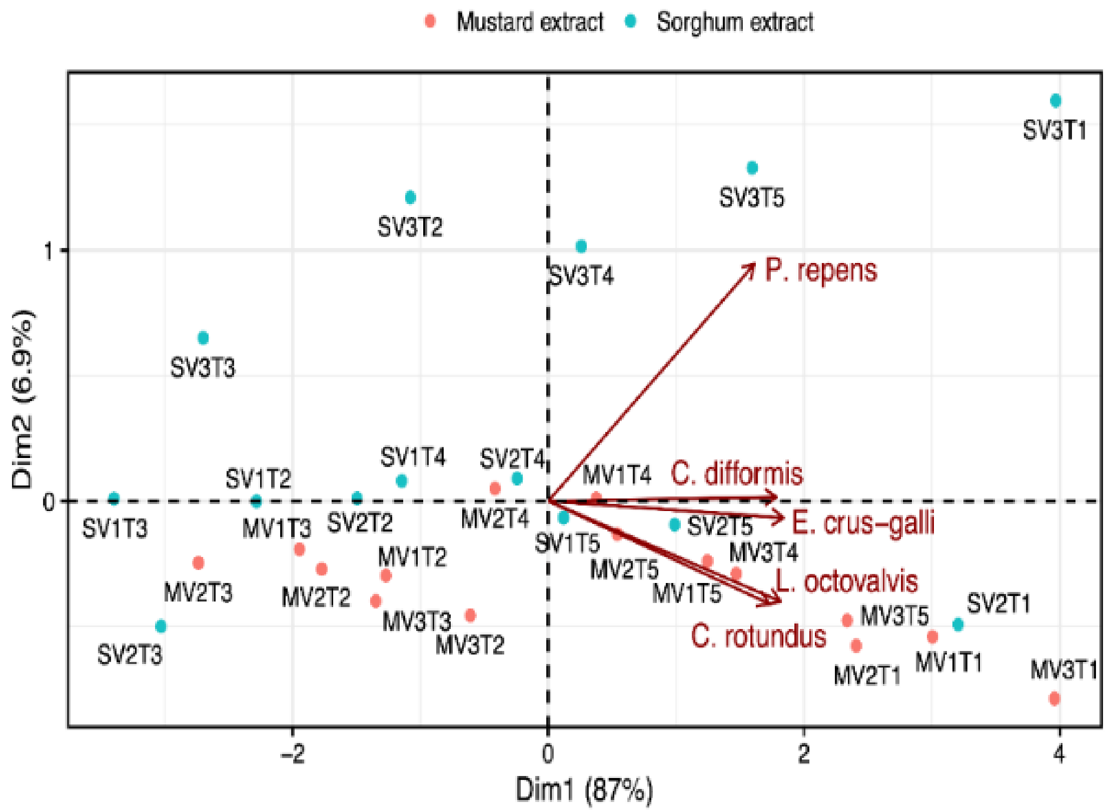

Fig. 1. Principal component analysis (PCA) biplot demonstrating the connection between the assessed parameters and the weed species. Dim1= PC1 on the x-axis explained 87% of the overall variation, whilst Dim1= PC2 on the y-axis explained 6.9% of the overall variation. The length of the arrows indicates the contribution of attributes to PC1 and PC2. The longer arrows represent components with greater contribution, while the darker shorter arrows represent components with a smaller contribution.

Here, S- Sorghum extract, M- Mustard extract, V_1 - BRRI dhan48, V_2 - BRRI dhan98, V_3 - Binadhan-21, T_1 - no weeding (control), T_2 - RDH at post emergence, T_3 - 80% of RDH at post emergence + boiled crop extracts, T_4- 70% of RDH at post emergence + boiled crop extract, T_5 -60% of RDH at post emergence + boiled crop extracts.

3.5 Comparison between two crop residues extracts of percent inhibition of weeds by radar graph

Different types of weeds were affected by four different treatments shown in Figure 2. These were RDH at post-emergence, 80% of RDH at post-emergence + boiled crop extracts, 70% of RDH at post-emergence + boiled crop extracts, and 60% of RDH at post-emergence + boiled crop extracts. Each radar chart represents the effect of different treatments using sorghum extract (a) and mustard extract (b) on weed species. The species of weeds included in the study are *C. rotundus*, *L. octovalvis*, *E. crus-galli*, *P. repens*, and *C. difformis*. The radar charts have a scale from 0 to 100, indicating the percentage of weed inhibition or control. Each radar chart has five points on the perimeter, each labelled with the name of a weed species. In both charts, each treatment (RDH at post-emergence to 60% of RDH at post-emergence + boiled crop extracts) is represented by a colored line, forming a polygon shape within the radar chart. The closer a line is to the outer edge of the chart, the more effective the treatment is for the corresponding weed. Comparing both chats, the highest percentage of weed inhibition (80.96%) was found in controlling *Cyperus difformis* when using the 80% RDH at post-emergence with boiled sorghum residue extract and the second highest percentage of weed inhibition (76.55%) was found in controlling *L. octovalvis* when using the same treatment. The overall trend in both charts is that the effectiveness goes down from RDH at post-emergence to 60% of RDH at post-emergence + boiled crop extracts. This suggests that higher concentrations of RDH combined with boiled crop extracts of sorghum are more effective than other treatments. The findings of this study are between variety selection, herbicide application rates, and the use of boiled sorghum extract in managing weed growth and enhancing rice yield. The interaction between variety and sorghum extract was found significantly influenced on DW of weeds, number of weeds and PI. The treatment BRRI dhan98 and no weeding had a large WP, whereas the treatment BRRI dhan48 and no weeding had the second highest WP. The treatment BRRI dhan48 and 80% of RDH at post emergence along with boiled crop extracts exhibited the highest percentage of weed inhibition, followed by Binadhan-21 and 80% of RDH at post emergence along with boiled crop extracts, BRRI dhan98 and 80% of RDH at post emergence along with boiled crop extracts. The smallest number was recorded in BRRI dhan48 and no weeding, BRRI dhan98 and no weeding, Binadhan-21 and no weeding respectively. The interaction between variety selection, herbicide rates, and sorghum extract application has multifaceted implications for rice yield. Varietal differences in response to reduced herbicide rates and sorghum extract highlight the need for tailored weed management strategies based on the chosen variety. The synergistic effects observed between certain varieties and sorghum extract indicate the possibility of enhancing weed control and yield simultaneously. These findings underscore the importance of customizing weed management practices to specific rice varieties for optimal yield outcomes **(Hossain *et al.*, 2017; Rahman *et al.*, 2020; Zinnat *et al.*, 2024).**

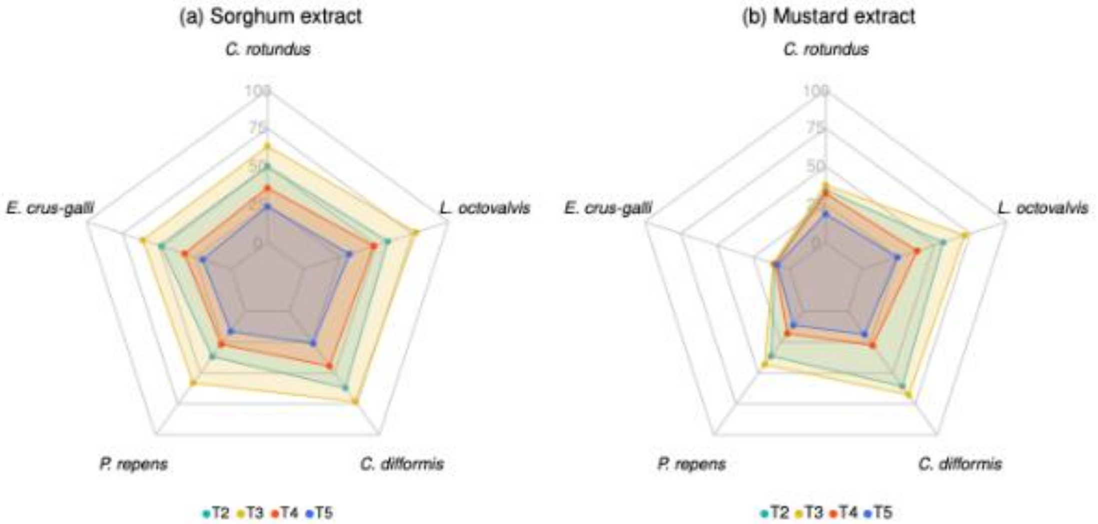

Fig. 2. Radar graph to illustrate sorghum extract and mustard extract in a network of percent inhibition of weeds. Contrasts between different classes of weed species on the vertex, percent inhibition of weeds on the *y*-axis.

Here, T_2 - RDH at post emergence, T_3 - 80% of RDH at post emergence + boiled crop extracts, T_4-70% of RDH at post emergence + boiled crop extract, T_5 -60% of RDH at post emergence + boiled crop extracts.

3.6 Comparison between the interaction effect of variety and reduced rate of herbicides along with boiled extract of crop residues on percent inhibition of weeds

The interaction between rice variety, boiled crop residue extracts (sorghum and mustard), and reduced herbicide rates significantly influenced percent inhibition (PI) of weed growth (Table 7).

Under boiled sorghum extract treatments, the highest PI for *Cyperus rotundus* (Mutha) was recorded in BRRI dhan48 (69.24%) with 80% RDH + boiled extract, followed by Binadhan-21 and BRRI dhan98 under similar treatments. For *Echinochloa crus-galli* (Shama), BRRI dhan98 showed the highest PI (64.42%), with Binadhan-21 and BRRI dhan48 closely following. For *Panicum repens* (Angta), BRRI dhan98 recorded the highest PI (60.09%), again followed by the same treatment in other varieties. Sabuj nakful inhibition was highest in BRRI dhan98 (80.96%) with 80% RDH + boiled extract, and similarly high in Binadhan-21 and BRRI dhan48. The highest PI for Pani long was observed in BRRI dhan48 (79.80%) under the same treatment, followed by Binadhan-21 and BRRI dhan98. Across all weed species, no-weeding treatments showed the lowest PI values, indicating minimal weed suppression. Under boiled mustard extract treatments, BRRI dhan98 with 80% RDH + boiled extract showed the highest PI for *C. rotundus* (40.67%), Shama (12.17%), Angta (46.48%), Sabuj nakful (75.00%), and Pani long (76.55%). Similar treatment combinations in Binadhan-21 and BRRI dhan48 also yielded relatively high inhibition values. As with sorghum, the lowest PI values were associated with no-weeding treatments. Overall, boiled sorghum extract with 80% RDH demonstrated greater weed suppression across all species and varieties, with notably higher PI values for Sabuj nakful (80.96%) and Pani long (79.80%) compared to mustard extract (75.00% and 76.55%, respectively). This highlights the superior and consistent efficacy of sorghum extract in integrated weed management for transplanted rice systems.The results demonstrated that the interaction between mustard extract application and reduced herbicide rates significantly affects weed populations (WP) and dry weight (DW), with notable variance among different rice varieties. The efficacy of mustard extracts, particularly when combined with 80% of the recommended dose of herbicide (RDH), in reducing the weed population and biomass across various species, including Mutha (*Cyperus rotundus*), Shama (*Echinochloa crus-galli*) and others, aligns with recent studies advocating for integrated weed management strategies that reduce reliance on chemical herbicides **(Azza *et al.*, 2020; Hia *et al.*, 2017; Jena *et al.*, 2002)**. These findings resonate with the broader trend toward sustainable agriculture, emphasizing the importance of alternative weed control methods that minimize environmental impacts **(Chauhan *et al.*, 2015; Tonni *et al.*, 2024).**

Table 7. Interaction effect of variety and boiled extract of crop residue and herbicide on percent inhibition of weeds.

% inhibition of weeds										
	Boiled extracts of sorghum					Boiled extract of mustard				
Interaction	Mutha (*C. rotundus*)	Shama (*E. crus-galli*)	Angta (*P. repens*)	Sabuj nakful (*C. difformis*)	Pani long (*L. octovalvis*)	Mutha (*C. rotundus*)	Shama (*E. crus-galli*)	Angta (*P. repens*)	Sabuj nakful (*C. difformis*)	Pani long (*L. octovalvis*)
V_1T_1	0.00f	0.00g	0.00g	0.00h	0.00g	0.00d	0.00h	0.00e	0.00f	0.00h
V_1T_2	57.62ab	47.45c	41.49b	55.55d	62.88b	34.83a	9.81c-e	36.11b	58.41b	54.91b-d
V_1T_3	69.24a	56.97a-c	54.82a	70.05b	79.80a	36.49a	11.06a-c	41.48ab	64.62b	70.48ab
V_1T_4	35.71cd	30.94de	25.75c-e	45.22e	57.00b-d	33.93a	9.58de	18.70cd	25.84cd	40.95d-f
V_1T_5	24.09de	15.84f	16.04ef	26.51g	37.12e	19.36bc	8.07fg	12.04cd	18.09de	22.86g
V_2T_1	0.00f	0.00g	0.00g	0.00h	0.00g	0.00d	9.00ef	0.00e	0.00f	0.00h
V_2T_2	36.49cd	49.61bc	29.89b-d	70.99b	59.92bc	37.35a	11.61ab	37.41ab	65.56ab	60.05a-c
V_2T_3	54.06b	64.42a	60.09a	80.96a	73.81a	40.67a	12.17a	46.48a	75.00a	76.55a
V_2T_4	33.93cd	32.23de	21.04d-f	46.13e	49.60d	34.00a	10.5b-d	19.26c	32.50c	47.32c-e
V_2T_5	19.36e	24.83d-f	12.52f	25.44g	33.73ef	20.84bc	10.07c-e	12.22cd	24.44cd	34.10e-g
V_3T_1	0.00f	0.00g	0.00g	0.00h	0.00g	0.00d	6.50h	0.00e	0.00f	0.00h
V_3T_2	56.05b	47.69c	38.56b	59.37c	51.52cd	31.35ab	9.50de	34.93b	57.86b	53.81b-d
V_3T_3	66.33ab	62.19ab	59.06a	68.45b	78.94a	36.29a	10.67b-d	40.94ab	63.53b	66.03ab
V_3T_4	37.82c	33.58d	33.21bc	41.44f	38.79e	28.41abc	8.78ef	15.58cd	24.42cd	26.51fg
V_3T_5	27.72c-e	18.80ef	20.11d-f	26.13g	23.84f	16.59c	6.86gh	9.13de	13.05e	16.99gh
Level of sig.	*	*	*	**	*	*	*	*	*	*
CV (%)	14.53	13.14	15.30	5.35	13.90	10.65	14.05	6.75	16.34	7.43

Here, means with the same letters within the same column do not differ significantly as per DMRT. * - Significant at 5% level of probability, here, **- Significant at 1% level of probability, V_1- BRRI dhan48, V_2 - BRRI dhan98, V_3 - Binadhan-21, T_1 - no weeding (control), T_2 - RDH at post emergence, T_3 - 80% of RDH at post emergence + boiled crop extracts, T_4-70% of RDH at post emergence + boiled crop extract, T_5 -60% of RDH at post emergence + boiled crop extracts

3.7 Comparison between the effect of variety on yield and yield contributing characters of T. *aus* rice

These three rice varieties exhibited significant differences in number of total tillers hill^{-1} (NTT), number of effective tillers hill^{-1} (NET), panicle length (PL), number of grains panicle^{-1}, thousand grain weight (TGW), biological yield (BY) and harvest index (HI) in both boiled sorghum and mustard extract treatments (Table 8). In boiled sorghum extract, the tallest having the higher NTT (12.20) and NET (10.58) than those of BRRI dhan48 (NTT 10.87, NET 8.47) and Binadhan-21 (NTT 10.38, NET 9.22). BRRI dhan98 also gave the longest panicles (20.69 cm), the highest NG (100.23) and the maximum TGW (23.37 g) followed by BRRI dhan48 (NG: 95.43, TGW: 22.00 g) and Binadhan-21 (NG: 89.69, TGW: 19.05 g). Conversely, the BY was maximum in BRRI dhan98 (9.94 t ha^{-1}) followed by BRRI dhan48 (9.09 t ha^{-1}) and Binadhan-21 (7.89 t ha^{-1}). HI was also maximum in BRRI dhan98 (44.04%) than BRRI dhan48 (43.67%) and Binadhan-21 (42.86%). In the similar trend, when treated with boiled mustard extract, the maximum NTT (12.24) and NET (10.67) followed by BRRI dhan48 (10.98 and 9.14) and Binadhan-21 (10.07 and 8.40). BRRI dhan98 possessed the highest NG (101.98) and TGW (23.11 g) and recorded the longest panicle

(20.85 cm) compared with those of BRRI dhan48 (NG: 99.34, TGW: 21.33 g) and Binadhan-21 (NG: 89.86, TGW: 19.10 g). BY was maximum in BRRI dhan98 (10.11 t ha^{-1}) followed by BRRI dhan48 (9.13 t ha^{-1}) and Binadhan-21 (7.45 t ha^{-1}). Trends of HI were somewhat same: BRRI dhan98 (44.04%), BRRI dhan48 (42.97%) and Binadhan-21 (42.39%). Overall, BRRI dhan98 consistently demonstrated superior agronomic performance across all measured parameters in both sorghum and mustard extract treatments. While the mustard extract treatment slightly reduced some parameters compared to the sorghum extract treatment, the relative performance among the varieties remained consistent, with BRRI dhan98 maintaining its lead. Among the three varieties, for varietal effect it was demonstrated that variety BRRI dhan48 demonstrated the best results. The percentage of weed inhibition varied from 47.36% to 24.71% across the varieties. Neither herbicide nor crop residues extracts produced better weed suppression, their combination had better performances. The study findings hold profound implications for weed management strategies in T. *aus* rice cultivation. They emphasize that variety selection is a pivotal consideration in designing effective weed control plans **(Kaes, 2015; Rahman *et al.*, 2024)**. Farmers can benefit from selecting varieties with inherent traits that discourage weed growth, thereby reducing the need for excessive herbicide application or labor-intensive weed removal practices. This approach aligns with the principles of integrated weed management and sustainable agriculture, where variety choice serves as an essential component of a comprehensive weed control strategy **(Kashyap *et al.*, 2021; Hamaad *et al.*, 2021; Nur-A-Alam *et al.*, 2024)**.

Table 8. Effect of variety on the yield contributing characters and yield of T. *aus* rice.

Boiled extracts of sorghum								Boiled extracts of mustard						
Variety	NTT $hill^{-1}$	NET $hill^{-1}$	PL (cm)	NG $panicle^{-1}$	TGW (g)	BY (t ha^{-1})	HI (%)	NTT $hill^{-1}$	NET $hill^{-1}$	PL (cm)	NG $panicle^{-1}$	TGW (g)	BY (t ha^{-1})	HI (%)
V_1	10.87b	8.47c	20.60ab	95.43b	22.00b	9.09b	43.67a	10.98b	9.14b	20.22b	99.34b	21.33b	9.13b	42.97b
V_2	12.20a	10.58a	20.69a	100.23a	23.37a	9.94a	44.04a	12.24a	10.67a	20.85a	101.98a	23.11a	10.11a	44.04a
V_3	10.38b	9.22b	20.09b	89.69c	19.05c	7.89c	42.86b	10.07c	8.406c	20.17b	89.87c	19.10c	7.45c	42.39b
Level of sig.	**	**	*	**	**	**	**	**	**	**	**	**	**	*
CV (%)	6.19	7.26	5.74	5.14	9.27	10.52	5.67	4.79	8.32	5.37	8.23	6.55	5.12	5.56

Here, means with the same letters within the same column do not differ significantly as per DMRT. * - Significant at 5% level of probability, here, **- Significant at 1% level of probability, V_1- BRRI dhan48, V_2 - BRRI dhan98, V_3 - Binadhan-2.

3.8 Comparison between effect of combination of reduced rate of herbicides along with boiled extract of crop residues on yield and yield contributing characters of T. *aus* rice

Boiled crop extracts combined with reduced herbicide rates significantly influenced number of total tillers $hill^{-1}$ (NTT), number of effective tillers $hill^{-1}$ (NET), panicle length (PL), number of grains $panicle^{-1}$ (NG), thousand grain weight (TGW), biological yield (BY), and harvest index (HI) (Table 9). Under boiled sorghum extract, the highest NTT (12.33), NET (11.11), NG (99.93), TGW (22.00 g), BY (10.86 t ha^{-1}), and HI (45.04%) were recorded in the 80% RDH + sorghum boiled extract treatment. This treatment also produced the longest panicles (21.19 cm). Full RDH and 70% RDH + boiled sorghum extract followed in most traits. In contrast, the lowest values were observed in the no-weeding control: NTT (9.64), NET (7.42), PL (20.06 cm), NG (94.39), TGW (20.04 g), BY (7.42 t ha^{-1}), and HI (41.30%) (Table 9). Under boiled mustard extract, the 80% RDH + mustard boiled extract treatment also outperformed others, recording the highest NTT (12.34), NET (11.30), PL (21.14 cm), NG (99.16), TGW (21.79 g), BY (10.34 t ha^{-1}), and HI (44.66%). The lowest performance was again observed in the no-weeding control: NTT (9.73), NET (7.56), PL (19.90 cm), NG (94.81), TGW (20.54 g), BY (7.06 t ha^{-1}), and HI (41.33%) (Table 9). Across both treatments, the application of 80% RDH combined with boiled crop extracts (either sorghum or mustard) consistently resulted in superior agronomic performance compared to control and other RDH levels. This highlights the effectiveness of combining reduced herbicide rates with boiled crop extracts in enhancing rice plant growth, yield, and overall productivity. The crops production is influenced by its individual characteristics. Consequently, the rise in GY is connected to improvements in features such as effective tillers $hill^{-1}$, Panicle length, grains $panicle^{-1}$ and 1000-grain weight etc. The data demonstrates that in the case of treatment 80% of RDH along with boiled crop extract, these yield-related attributes were superior to those of the other varieties. The combination between crop residues extracts and herbicide was claimed to have a substantial impact on weed control and yield **(Sarker *et al.*, 2021; Mim *et al.*, 2024)**.

Table 9. Effect of boiled extract of sorghum crop residue and reduced rate of herbicide on the yield contributing characters and yield of T. *aus* rice.

Boiled extracts of sorghum								Boiled extracts of mustard						
Treatments	NTT hill^{-1}	NET hill^{-1}	PL (cm)	NG panicle^{-1}	TGW (g)	BY (t ha^{-1})	HI (%)	NTT hill^{-1}	NET hill^{-1}	PL (cm)	NG panicle^{-1}	TGW (g)	BY (t ha^{-1})	HI (%)
T_1	9.93c	7.74d	20.00b	88.94e	20.78d	6.61e	41.42d	9.73d	7.56d	19.90c	94.81c	20.54c	7.06d	41.33c
T_2	11.67ab	10.07b	20.53ab	97.46b	21.80ab	9.86b	44.53a	11.70b	10.31b	20.68ab	98.64a	21.40ab	9.47b	44.18ab
T_3	12.33a	11.11a	21.19a	99.93a	22.00a	10.86a	45.04a	12.34a	11.30a	21.14a	99.16a	21.79a	10.34a	44.66a
T_4	11.26b	9.44b	20.42b	95.92c	21.58b	9.00c	43.74b	11.31b	9.62b	20.44b	96.47b	21.21b	9.17b	43.58a-c
T_5	10.56c	8.74c	20.17b	93.34d	21.20c	8.54d	42.88c	10.40c	8.33c	19.93c	96.24b	20.96bc	8.46c	41.9bc
Level of sig.	**	**	*	**	**	**	**	**	**	**	**	**	**	*
CV (%)	6.19	7.26	5.74	5.14	9.27	10.52	5.67	4.79	8.32	5.37	8.23	6.55	5.12	5.56

Here, means with the same letters within the same column do not differ significantly as per DMRT. * - Significant at 5% level of probability, here, **- Significant at 1% level of probability, T_1 - no weeding (control), T_2 - RDH at post emergence, T_3 - 80% of RDH at post emergence + boiled crop extracts, T_4-70% of RDH at post emergence + boiled crop extract, T_5 -60% of RDH at post emergence + boiled crop extracts.

3.9 Comparison between the interaction effect of variety and combination of reduced rate of herbicides along with boiled extract of crop residues on yield and yield contributing characters of T. *aus* rice

The study examined the combined effects of variety and reduced rate of herbicides along with boiled extract of sorghum and mustard on yield and yield contributing characters of T. *aus* rice. The HI, NG, PL and NET were significantly influenced (Table 10). Under boiled sorghum extract, the tallest plants were recorded in BRRI dhan48 (105.89 cm) and BRRI dhan98 (104.56 cm) with 80% RDH + extract. The shortest plants were found in Binadhan-21 under no weeding (87.00 cm). Maximum tillers hill^{-1} (12.78) and NET (11.78) were also observed in BRRI dhan98 under the same treatment, while Binadhan-21 with no weeding produced the lowest NTT (9.11) and NET (6.78). Panicle length was highest in BRRI dhan48 (21.44 cm) and BRRI dhan98 (21.42 cm), and shortest in Binadhan-21 with 60% RDH (19.67 cm). BRRI dhan98 recorded the highest NG (105.59), TGW (24.13 g), BY (11.63 t ha^{-1}), and HI (46.04%) when treated with 80% RDH + sorghum extract, while Binadhan-21 under no weeding had the lowest values for NG (85.53), TGW (18.83 g), BY (5.37 t ha^{-1}), and HI (39.76%). Similarly, under boiled mustard extract, BRRI dhan98 with 80% RDH + extract exhibited superior performance across all traits such as, PH (104.82 cm), NTT (13.08), NET (12.17), NG (105.52), TGW (24.00 g), BY (11.61 t ha^{-1}), and HI (45.45%). In contrast, Binadhan-21 under no weeding recorded the lowest values, viz. PH (87.50 cm), NTT (8.50), NET (6.50), NG (88.71), TGW (18.80 g), BY (6.17 t ha^{-1}), and HI (40.57%) (Table 10).

The yield of a crop depends on component crop characters. Thus, the increase in GY can be attributed to the increase in yield attributes like effective tillers hill^{-1}, Panicle length, grains panicle^{-1} and 1000-grain weight etc. It was found that in the variety BRRI dhan98, those yield attributes were higher than the other varieties. The study found that sorghum crop residues at 2.0 t/ha effectively controlled weeds and enhanced rice production in the BR11 cultivar. Weed inhibition ranged from 46.84% to 66.94% across various species, including Pani kachu and Shama. Under this treatment, BR11 achieved the highest grain yield of 5.76 t/ha and straw yield of 6.39 t/ha. It also recorded the best performance metrics with 8.41 effective tillers per hill, 118.08 grains per panicle, and a 1000-grain weight of 20.54 g. These results indicate that sorghum residues are a viable natural herbicide alternative for sustainable agriculture in Bangladesh **(Rahman *et al.*, 2020; Dola *et al.*, 2024)**. **Salma *et al.* (2017) and Islam *et al.* (2024)** analyzed the effects of variety and planting density on weed management and rice yield. BR25 significantly excelled in weed control, showing the lowest weed density and dry weight, especially at closer planting densities. It also led in yield traits, with a plant height of 157.9 cm, panicle length of 24.94 cm, 103.10 grains per panicle, 29.36 sterile spikelets per panicle, a grain yield of 4.30 t/ha, and a straw yield of 8.99 t/ha. Conversely, BRRI dhan62 had the highest number of tillers per hill, Binadhan-7 had the heaviest 1000-grain weight at 25.21 g, and BRRI dhan56 achieved the highest harvest index at 53.50%. These results highlight BR25's effectiveness in both yield enhancement and weed suppression when planted at denser spacing. Another study investigated the effects of different crop residue treatments on weed control and rice yield. It found that weed growth was highest with no residue treatment and lowest when 0.5 t/ha buckwheat and 1.0 t/ha marsh pepper residues were used. BRRI dhan56, one of the tested varieties, showed the best performance, yielding the highest grain and straw outputs under the 0.5 t/ha buckwheat and 1.0 t/ha marsh pepper residue treatment. This treatment also resulted in the highest number of effective tillers per hill, grains per panicle, and 1000-grain weight. The results indicate that a combination of buckwheat and marsh pepper residues is effective for sustainable weed management and enhancing rice production **(Afroz *et al.*, 2018; Alam *et al.*, 2024). Ahmed *et al.* (2018)** and **Akondo *et al.* (2024)** focused on the effects of sorghum crop residue extracts and wheat varieties on weed control and yield. BARI Gom-21, one of the varieties tested, showed minimal weed growth and the highest yields. Hand weeding proved most effective for controlling weeds, followed by sorghum residue extract at a 1:20 (w/v) ratio, which achieved weed inhibition rates of 51.10% to 75.27% across various species. The lowest yields were in plots without the extract. Overall, BARI Gom-21 performed best under all treatments, demonstrating that sorghum residue extract is a potent and sustainable option for weed management in wheat cultivation.

Table 10. Interaction effect of variety and boiled extract of sorghum crop residue and herbicide on the yield contributing characters and yield of T. *aus* rice.

Boiled extracts of sorghum								Boiled extract of mustard						
Interaction	**NTT hill^{-1}**	**NET hill^{-1}**	**PL (cm)**	**NG panicle^{-1}**	**TGW (g)**	**BY (t ha^{-1})**	**HI (%)**	**NTT hill^{-1}**	**NET hill^{-1}**	**PL (cm)**	**NG panicle^{-1}**	**TGW (g)**	**BY (t ha^{-1})**	**HI (%)**
V_1T_1	9.44ef	6.78h	20.07ab	88.81h	21.33f	6.80i	42.54ef	9.52gh	7.17gh	19.17g	97.04e	20.67e	6.92gh	41.17bc
V_1T_2	11.33b-d	9.00de	20.63ab	98.00d	22.33cd	9.64c	44.35bc	11.44c-e	9.81c-e	20.23c-e	100.71b	21.44de	10.00cd	44.33a-c
V_1T_3	12.11a-c	10.33bc	21.44a	101.65c	22.57bc	11.22b	44.38bc	12.30a-c	11.06a-c	21.29a	101.02b	22.14cd	10.79b	44.46a-c
V_1T_4	11.11cd	8.44e-g	20.51ab	95.57e	21.92e	9.15d	44.11b-d	11.25d-f	9.58de	20.11d-f	99.04cd	21.28de	9.43d	43.48a-c
V_1T_5	10.33de	7.78f-h	20.36ab	93.11f	21.83e	8.64e	42.94c-f	10.41fg	8.07fg	20.31b-d	98.90d	21.11e	8.52e	41.42bc
V_2T_1	11.22cd	8.89d-f	20.33ab	92.48f	22.17de	7.65g	41.96f	11.17d-f	9.00ef	21.07ab	98.69d	22.17cd	8.09ef	42.25a-c
V_2T_2	12.67a	11.33ab	20.65ab	103.63b	23.90a	11.11b	45.15ab	12.67ab	11.61ab	20.82a-d	104.64a	23.47ab	10.73bc	44.75ab
V_2T_3	12.78a	11.78a	21.42a	105.59a	24.13a	11.63a	46.04a	13.08a	12.17a	21.13a	105.52a	24.00a	11.61a	45.45a
V_2T_4	12.44ab	11.00a-c	20.61ab	101.59c	23.77a	9.71c	43.99b-e	12.29a-c	10.50b-d	21.09ab	100.74b	23.10ab	10.50bc	44.52a-c
V_2T_5	11.89a-c	9.89cd	20.47ab	97.86d	22.90b	9.60c	43.07c-f	12.02b-d	10.07c-e	20.15de	100.33bc	22.83bc	9.63d	43.22a-c
V_3T_1	9.11f	7.56gh	19.61b	85.53i	18.83h	5.37j	39.76g	8.50i	6.50h	19.46e-g	88.71h	18.80f	6.17h	40.57c
V_3T_2	11.00cd	9.89cd	20.31ab	90.75g	19.17gh	8.84e	44.09b-d	11.00ef	9.50de	20.98a-c	90.56fg	19.29f	7.67fg	43.47a-c
V_3T_3	12.11a-c	11.22ab	20.71ab	92.54f	19.30g	9.71c	44.69ab	11.67c-e	10.67b-d	20.99a-c	90.93f	19.23f	8.63e	44.07a-c
V_3T_4	10.22d-f	8.89d-f	20.16ab	90.60g	19.07gh	8.15f	43.13c-f	10.39fg	8.78ef	20.11d-f	89.64f-h	19.27f	7.57fg	42.76a-c
V_3T_5	9.45ef	8.56e-g	19.67b	89.04h	18.87h	7.38h	42.61d-f	8.79hi	6.86gh	19.33fg	89.49gh	18.93f	7.23g	41.06bc
Level of sig.	*	*	*	**	**	**	*	*	*	**	**	*	*	*
CV (%)	6.19	7.26	5.74	5.14	9.27	10.52	5.67	4.79	8.32	5.37	8.23	6.55	5.12	5.56

Here, means with the same letters within the same column do not differ significantly as per DMRT. * - Significant at 5% level of probability, here, ** - Significant at 1% level of probability, V_1 - BRRI dhan48, V_2 - BRRI dhan98, V_3 - Binadhan-21, T_1 - no weeding (control), T_2 - RDH at post emergence, T_3 - 80% of RDH at post emergence + boiled crop extracts, T_4-70% of RDH at post emergence + boiled crop extracts, T_5 -60% of RDH at post emergence + boiled crop extract.

3.10 Effect of variety, combination of reduced rate of herbicides along with boiled extract of sorghum and interaction between variety and treatments on GY and SY

The research showed significant differences in GY and SY throughout the three varieties. BRRI dhan98 variety had a maximum yield of 4.40 t ha^{-1}, likely due to its lower number of sterile spikelets panicle^{-1}. The variety Binadhan-21 had the lowest yield 3.40 t ha^{-1}. The three varieties have a considerable impact on SY. The SY was highest at 5.54 t ha^{-1} in BRRI dhan98 and lowest at 4.50 t ha^{-1} in Binadhan-21 (Fig. 3A). According to the study, boiled extracts significantly affected both GY and SY. 80% of RDH along with boiled sorghum crop residue extracts produced the highest yield (4.87 t ha^{-1}), while the treatment no weeding produced the lowest yield (2.75 t ha^{-1}). Also 80% RDH along with boiled sorghum crop residue extracts had the maximum SY of 5.98 t ha^{-1}, whereas the no weeding treatment had the lowest SY of 3.86 t ha^{-1} (Fig. 3B). Interaction between varieties and boiling extract with reduced herbicide rates significantly affected GY and SY. BRRI dhan98 and 80% RDH along with boiled sorghum crop residue extracts resulted in the most significant GY. Conversely, the Binadhan-21 and 80% RDH at along with boiled sorghum crop residue extracts treatment yielded the lowest, employing Binadhan-21 with no weeding. BRRI dhan98 and 80% of RDH along with boiled sorghum crop residue extracts treatment resulted in the maximum SY, while the Binadhan-21 and no weeding treatment produced the lowest amount of SY (Fig. 3C). The boiled mustard extract treatments not only significantly reduced weed competition but also favourably influenced rice growth parameters and yield. BRRI dhan98 showed superior performance across most metrics, including plant height, number of tillers, and yield components, when treated with mustard extracts and reduced herbicide rates. This supports the notion that the choice of rice variety is crucial when implementing integrated weed management (IWM) strategies, as genetic differences can influence the effectiveness of such interventions **(Maity and Mukherjee, 2008; Ali *et al.*, 2010; Hossain *et al.*, 2024).**

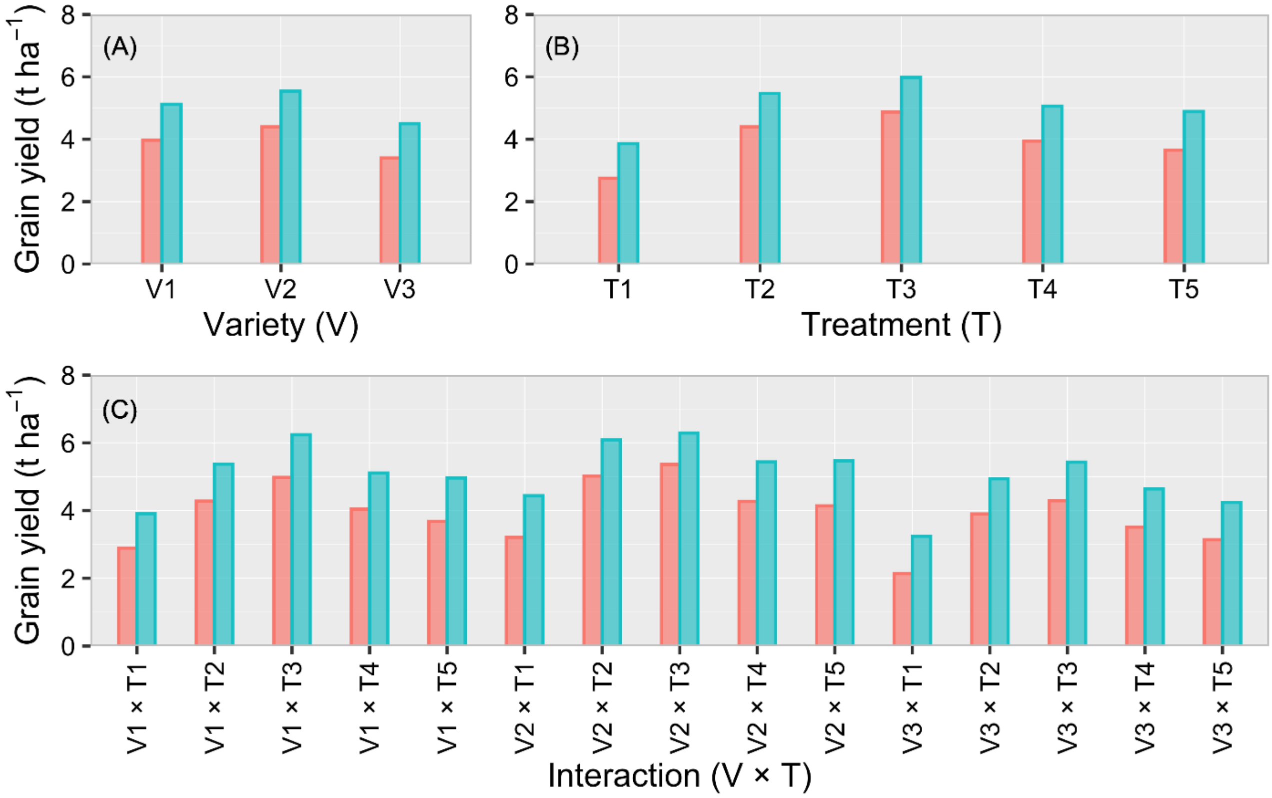

Fig. 3. (A) Effect of variety on grain and straw yields of T. *aus* rice; (B) Effect of boiled extract of sorghum crop residue and herbicide on grain and straw yields of T. *aus* rice; (C) Interaction effect of variety and boiled extract of sorghum crop residue and herbicide on grain and straw yields of T. *aus* rice, here, V_1 = BRRI dhan48, V_2 = BRRI dhan98, V_3 = Binadhan-21, T_1 = no weeding (control), T_2 = RDH at post emergence, T_3 = 80% of RDH at post emergence + boiled crop extracts, T_4=70% of RDH at post emergence + boiled crop extract, T_5 =60% of RDH at post t emergence + boiled crop extract.

3.11 Effect of variety, combination of reduced rate of herbicides along with boiled extract of mustard and interaction between variety and treatments on GY and SY

The research showed significant differences in GY and SY throughout the three varieties. BRRI dhan98 variety had a maximum yield of 4.47 t ha^{-1}, likely due to its lower number of sterile spikelets panicle^{-1}. The variety Binadhan-21 had the lowest yield 3.17 t ha^{-1}. The three varieties have a considerable impact on SY. The SY was highest at 5.65 t ha^{-1} in BRRI dhan98 and lowest at 4.29 t ha^{-1} in Binadhan-21 (Fig. 4A). According to the study, boiled extracts significantly affected both GY and SY. 80% of RDH along with boiled mustard crop residue extracts, produced the highest yield (4.62 tha^{-1}), while the treatment no weeding produced the lowest yield (2.93 t ha^{-1}) and 80% RDH along with boiled mustard crop residue extracts had the maximum SY of 5.72 t ha^{-1}, whereas the no weeding treatment had the lowest SY of 4.13 t ha^{-1} (Fig. 4B). Interaction between varieties and boiling extract with reduced herbicide rates significantly affected GY and SY. BRRI dhan98 and 80% of RDH along with boiled mustard crop residue extracts, produced the highest yield (5.28 tha^{-1}), while combination of BRRI dhan98 and no weeding produced the lowest yield (2.51 t ha^{-1}) and BRRI dhan98 and 80% RDH along with boiled mustard crop residue extracts had the maximum SY of 6.33 t ha^{-1}, whereas the no weeding treatment had the lowest SY of 3.67 t ha^{-1} (Fig. 4C). The differential response of rice varieties to mustard extract and herbicide treatments highlights the complexity of interactions between plant genotype, weed control practices, and environmental factors. The sensitivity of Binadhan-21 to weed competition and its lower responsiveness to treatments compared to BRRI dhan98 and BRRI dhan48 suggests that variety selection should be an integral part of weed management strategies in rice cultivation, tailoring practices to the specific strengths and vulnerabilities of each variety **(Nomun *et al.*, 2020; Salma *et al.*, 2017; Arif *et al.*, 2025).**

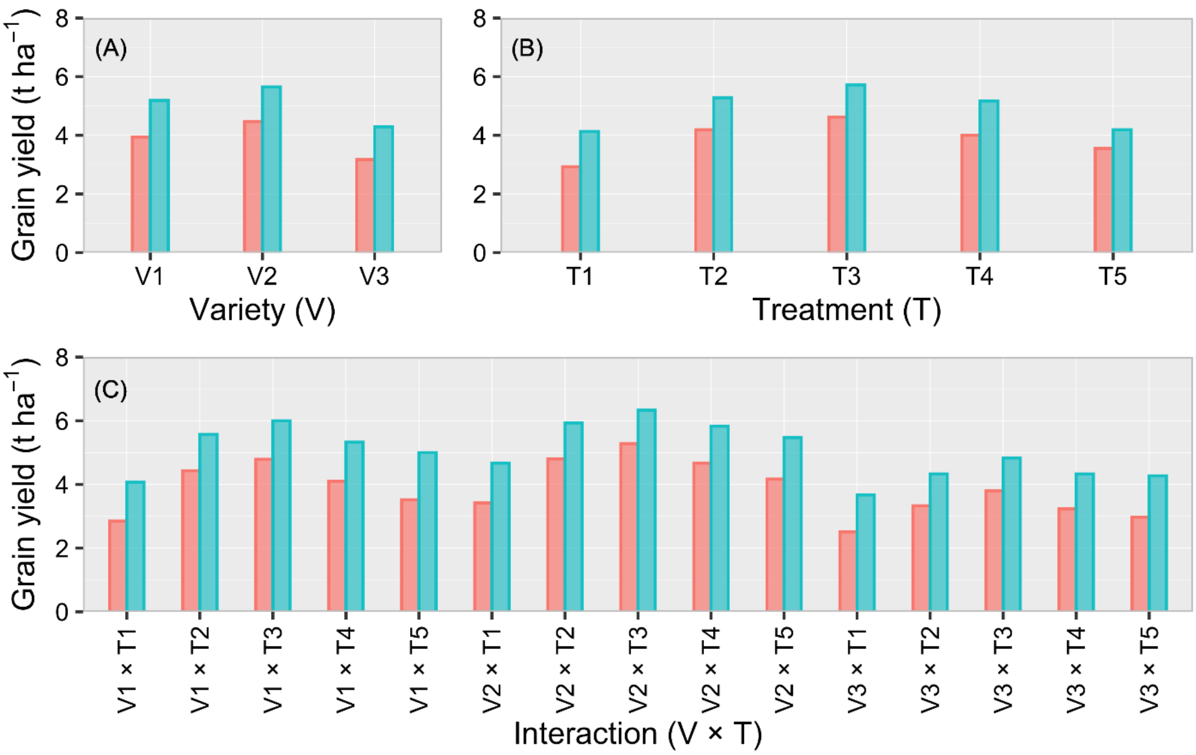

Fig. 4. (A) Effect of variety on grain and straw yields of T. *aus* rice; (B) Effect of boiled extract of mustard crop residue and herbicide on grain and straw yields of T. *aus* rice; (C) Interaction effect of variety and boiled extract of mustard crop residue and herbicide on grain and straw yields of T. *aus* rice, here, V_1 = BRRI dhan48, V_2 = BRRI dhan98, V_3 = Binadhan-21, T_1 = no weeding (control), T_2 = RDH at post emergence, T_3 = 80% of RDH at post emergence + boiled crop extracts, T_4=70% of RDH at post emergence + boiled crop extract, T_5 =60% of RDH at post t emergence + boiled crop extract.

4. Conclusion

The study shows that incorporating sorghum crop residues with reduced herbicide rates can significantly suppress weed populations, particularly in the BRRI dhan98 variety. The treatment with 80% recommended doses of herbicide at post emergence and sorghum boiled extracts showed the most effective results. This approach could reduce reliance on synthetic herbicides and potentially combat herbicide-resistant weeds, making sorghum extracts a promising weed management tool.

Consent for publication:

All authors declare their consent for publication.

Author contribution:

Author Contributions: Conceptualization: M.T.A., M.R.U., and M.A.S.; methodology, data collection and original data analysis: M.T.A.; data presentation, writing: M.T.A., M.K.; reviewing and editing: U.K.S., M.R.U., M.S.I and M.A.S. funding acquisition: M.R.U. All authors have read and agreed to the published version of the manuscript.

Conflicts of Interest:

The author declares no conflict of interest.

References

Absy, R., Abd EL-Fattah, H. (2022) Comparative performance of herbicides for grassy weed management in winter wheat (*Triticum aestivium* L.) under Egyptian conditions. *Egyptian Journal of Agronomy*, 44(1): 75–81. 10.21608/agro.2022.119473.1303

Afroz, F., Uddin, M. R., Hasan, A. K., Sarker, U. K., Hoque, M. M. I., Islam, M. A. (2018) Combined allelopathic effect of buckwheat and marsh pepper residues on weed management and crop performance of transplant aman rice. *Archives of Agriculture and Environmental Science,* 3: 289–296.

Ahmed, F., Uddin, M. R., Hossain, M. D., Sarker, U. K., Sarkar, D., Chadny, D. N. (2018) Effect of b extract of sorghum crop residues on weed management and crop performance of wheat. *Journal of Agronomy,* 21(2): 87–95.

Ahmed, S., Mamun, A. A., Islam, M. M., Hossain, S. M. A. (1986) Critical period of weed competition of transplanted aman rice. *Bangladesh Journal of Agricultural,* 11: 1–7.

Akondo, S., Ahmed, M. T., Uddin, M. R., Sarker, U. K. (2024) Combined application of herbicide and aqueous extract of sorghum and mustard crop residue enhance weed management and yield of wheat. *Journal of Agroforestry and Environment,* 17(2): 1–11.https://doi.org/10.55706/jae1710

Alam, M. S., Ahmed, M. T., Sarker, U. K., Begum, M., Uddin, M. R. (2024) Hot water extract of lentil enhances weed control efficiency and yield of boro rice under subtropical condition. *Journal of Agricultural Sciences and Engineering,* 6(3): 164–175.https://doi.org/10.48309/JASE.2024.471425.1051

Ali, M., Sardar, M. S. A., Biswas, P. K. (2010) Weed control and yield of transplanted aman rice as affected by integrated weed management and spacing. *Bangladesh Journal of Weed Science,* 1(1): 33–40.

Anon. (2018). *Bangladesh Economic Review 2018*. Economic Adviser's Wing, Finance Division, Ministry of Finance, Government of the People's Republic of Bangladesh.

Arif, N. R., Rahat, R. A., Khatun, M., Ridoy, M. Y. A. K., Ahmed, M. T., Talukder, N. K., Sarker, U. K., Hasan, A. K., Uddin, M. R. (2025) Impact of reduced rate of pre-emergence herbicide with aqueous extract of mustard crop residues on different weed management indices and yield of transplanted aman rice. *Archives of Agriculture and Environmental Science,* 10(1): 103–112.https://dx.doi.org/10.26832/24566632.2025.1001015

Ashraf, S., Sarker, U. K., Perveen, S., Shah, M. S. I., Azam, G., Uddin, M. R. (2021) Weed control efficacy of combined application of grass pea and mustard crop residues in T. aman rice. *Archives of Agriculture and Environmental Science*, 6(2): 134–141. https://doi.org/10.26832/24566632.2021.060204

Azza, K. E., El-Hassan, R. G., Sharshar, A. (2020) Improving the efficiency of herbicides by adding mineral oil on maize (*Zea mays* L.) crop and associated weeds. *Egyptian Journal of Agronomy*, 42(2): 151-162. 10.21608/agro.2020.27108.1209

Bangladesh Bureau of Statistics (BBS). (2022) *Yearbook of Agricultural Statistics of Bangladesh*. Ministry of Planning, Government of the People's Republic of Bangladesh.

Bangladesh Bureau of Statistics (BBS). (2023) *Yearbook of Agricultural Statistics of Bangladesh*. Ministry of Planning, Government of the People's Republic of Bangladesh.

Bangladesh Institute of Nuclear Agriculture (BINA). (2022) *Annual report for 2021*. BINA, BAU Campus, Mymensingh-2202, Bangladesh.

Bangladesh Rice Research Institute (BRRI). (2017) *Weed management in mechanically transplanted rice identifying the cost savings practices.* (pp. 1–52). BRRI, Joydebpur, Gazipur, Bangladesh.

Bangladesh Rice Research Institute (BRRI). (2018) *Annual report for 2017* (pp. 28–35). BRRI, Joydebpur, Gazipur, Bangladesh.

Bangladesh Rice Research Institute (BRRI). (2020) *Annual report for 2019*. BRRI, Joydebpur, Gazipur, Bangladesh.

Belz, R. G. (2004) *Evaluation of allelopathic traits in Triticum L. spp and Secale cereal L.* (PhD thesis). University of Hohenheim, Stuttgart, Germany.

Biswas, B., Timsina, J., Garai, S., Mondal, M., Banerjee, H., Adhikary, S., Kanthal, S. (2020) Weed control in transplanted rice with post-emergence herbicides and their effects on subsequent rapeseed in eastern India. *International Journal of Pest Management*, 69(1): 89–101. https://doi.org/10.1080/09670874.2020.1853276

Blackshaw, R. E., Moyer, J. R., Harker, K. N., Clayton, G. W. (2005) Integration of agronomic practices and herbicides for sustainable weed management in a zero-till barley–field pea rotation. *Weed Technology*, 19(1): 190–196. https://doi.org/10.1614/WT-04-128R

Chauhan, B. S., Ahmed, S., Awan, T. H., Jabran, K., Manalil, S. (2015) Integrated weed management approach to improve weed control efficiencies for sustainable rice production in dry-seeded systems. *Crop Protection*, 71: 19–24.

Chipomho, J., Parwada, C., Rugare, J. T., Mabasa, S., Chikowo, R., Mashingaidze, A. B. (2021) Influence of Soil Organic Carbon, fertilizer management, and weeding regime on weed dynamics and maize productivity on sandy soils in eastern Zimbabwe. *South African Journal of Plant and Soil*, 38(2): 81–92. https://doi.org/10.1080/02571862.2020.1845831

Cruz, E. D., Moody, K., Ramos, M. B. D. (1986) Reducing variability by sampling weeds in upland rice (*Oryza sativa*). *Philippine Journal of Weed Science*, 13: 56–59.

Dentika, P., Ozier-Lafontaine, H., Penet, L. (2021) Weeds as pathogen hosts and disease risk for crops in the wake of a reduced use of herbicides: Evidence from yam (*Dioscorea alata*) fields and *Colletotrichum* pathogens in the tropics. *Journal of Fungi*, 7(4): 283. https://doi.org/10.3390/jof7040283

Dola, N. A., Sarker, U. K., Ahmed, M. T., Upama, S. A., Rashid, M. H. O., Uddin, M. R. (2024) Comparative advantages of aqueous extract of mustard crop residues with herbicide to weed control and crop performance of wheat. *Archives of Agriculture and Environmental Science*, 9(2): 294–301.https://doi.org/10.26832/24566632.2024.0902013

FAO., UNDP. (1988) *Land resources appraisal of Bangladesh for agricultural development: Agro-ecological regions of Bangladesh* (Report 2, pp. 212–221). BARC/UNDP.

Ferdousi, S., Uddin, M. R., Begum, M., Sarker, U. K., Hossain, M. N., Hoque, M. M. I. (2017) Herbicidal activities of wheat residues in transplant aman rice. *Progressive Agriculture*, 28: 253–261.

Gomez, K. A., Gomez, A. A. (1984) Duncan's multiple range test. In *Statistical procedures for agricultural research* (2nd ed., pp. 202–215). Wiley.

Hamaad, R. F., Elkhiat, Z. K., Ibrahim, N. A. (2021) Physicochemical and phytotoxic studies of arena 7% od herbicide on some morphological parameters of common wheat (*Triticum aestivum* L.). *Egyptian Journal of Agronomy*, 43(3): 357–367. 10.21608/agro.2021.95029.1279

Hia, M. A., Mominul Islam, A. K., Sarkar, S. K., Anwar, M. P. (2017) Effectiveness of integrated weed management in five varieties of aromatic rice in Bangladesh. *Archives of Agriculture and Environmental Science*, 2(4): 308–314.

Hossain, M. N., Uddin, M. R., Salam, M. A., Sarker, U. K., Ferdousi, S., Uddin, M. J. (2017) Allelopathic potential of mustard crop residues on weed management and performance of transplant aman rice. *Journal of Bangladesh Agricultural University*, 15: 133–139.

Hossain, M. Z., Ahmed, M. T., Sarker, U. K., Rahman, M. S., Hossain, M. D., Uddin, M. R. (2024) Effectiveness of pre-emergence herbicides on weed population and yield of boro rice (cv. BRRI dhan58) under different dose. *Archives of Agriculture and Environmental Science*,9(4): 653–660. https://dx.doi.org/10.26832/24566632.2024.090403

Islam, T., Ahmed, M. T., Upama, S. A., Ridoy, M. Y. A. K., Rahat, R. A., Sarker, U. K., Rahman, M. S., Begum, M., Uddin, M. R. (2024) Presumption of herbicide resistant weeds and yield of Boro rice as influenced by pre- and postemergence herbicides. *Journal of Agroforestry and Environment*, 17(2): 87–96.https://doi.org/10.55706/jae1722

Jena, S. N., Tripathy, S., Sarangi, S. K., Biswal, S. (2002) Integrated weed management in direct seedbed rainfed lowland rice. *Indian Journal of Weed Science*, 34(1–4): 32–35.

Kaes, I. (2015) *Evaluation of herbicidal efficacy and residual activity on direct seeded boro rice* (MS thesis). Sher-e-Bangla Agricultural University, Dhaka, Bangladesh.

Kashyap, S., Singh, V. P., Guru, S. K., Pratap, T., Singh, S. P., Kumar, R. (2021) Effect of integrated weed management on weed and yield of direct seeded rice. *Indian Journal of Agricultural Research*, 56(1): 33–37.

Khanh, T. D., Chung, M. I., Xuan, T. D., Tawata, S. (2005) The exploitation of crop allelopathy in sustainable agricultural production. *Journal of Agronomy and Crop Science*, 191: 172–184.

Kumar, K., Goh, K. M. (2000) Crop residues and management practices: Effects on soil quality, soil nitrogen dynamics, crop yield, and nitrogen recovery. *Advances in Agronomy*, 68: 197–319.

Loureiro, I., Santin-Montanyá, I., Escorial, M.-C., García-Ruiz, E., Cobos, G., Sánchez-Ramos, I., Pascual, S., González-Núñez, M., Chueca, M.-C. (2019a) Glyphosate as a tool for the incorporation of new herbicide options in integrated weed management in Maize: A weed dynamics evaluation. *Agronomy*, 9(12): 876. https://doi.org/10.3390/agronomy9120876

Maity, S. K., Mukherjee, P. K. (2008) Integrated weed management in dry direct seeded rainy season rice (*Oryza sativa*). *Indian Journal of Agronomy*, 53: 116–120.

Mamun, A. A. (1990) Weeds and their control: A review of weed research in Bangladesh. *Journal of School Administration Research and Development*, 19: 45–72.

Mim, T. A., Ahmed, M. T., Sarker, U. K., Uddin, M. R. (2024) Evaluation of transplanted Aman rice by exploiting and adjusting existing technologies. *Archives of Current Research International*, 24(8): 43–51. https://doi.org/10.9734/acri/2024/v24i8847

Mitra, B., Patra, K., Bhattacharya, P. M., Ghosh, A., Chowdhury, A. K., Dhar, T., Islam, S., Laing, A. M., Gathala, M. K. (2022) Efficacy of pre- and post-emergence herbicide combinations on weed control in no-till mechanically transplanted rice. *Cogent Food & Agriculture*,8(1). https://doi.org/10.1080/23311932.2022.2139794

Moody, K. (1995) Sustainability in rice weeds management. *Asian-Pacific Weed Science Conference*, 15: 93–103.

Mostofa, G., Sarker, U. K., Ahmed, M. T., Salam, M. A., Uddin, M. R. (2024) Dose response of post-emergence herbicides for prediction of herbicide-resistant weeds and yield of Boro rice (cv. BRRI dhan58). *Journal of Agroforestry and Environment*, 17(2): 28–38. https://doi.org/10.55706/jae1714

Nomun, M. A. A., Uddin, M. R., Hasan, A. K., Rahman, M. S., Kaisar, N., Talukder, F. U. (2020) Efficacy of variety and mustard crop residues on weed management and crop performance of transplant aman rice. *Journal of Wastes and Biomass Management*, 2(2): 33–40.

Nur-A-Alam, M., Ahmed, M. T., Sarker, U. K., Rahman, M. R., Uddin, M. R. (2024) Assessing herbicide-resistance and yield optimization in Boro rice through post-emergence herbicide applications. *Asian Journal of Research in Crop Science,* 9(3): 22–36. https://doi.org/10.9734/ajrcs/2024/v9i3285

Pramanik, S. K., Uddin, M. R., Sarker, U. K., Sarkar, D., Ahmed, F., Alam, M. J. (2019) Allelopathic potential of marsh pepper residues for weed management and yield of transplant aman rice. *Journal of Progressive Agriculture*, 30(4): 379–386.

R Core Team. 2022 R: a language and environment for statistical computing (Vienna, Austria: R Foundation for Statistical Computing). Available at: https://www.r-project.org/

Rahman, M., Sarker, U. K., Ahmed, M. T., Zinnat, M., Alam, M. S., Uddin, M. R. (2024) Combined hot water extract of lentil and grass pea increase weed control efficiency and yield of boro rice. *Archives of Agriculture and Environmental Science,* 9(3): 500–507. https://doi.org/10.26832/24566632.2024.0903013.

Rahman, S. H., Uddin, Md. R., Salam, Md. A., Sarker, U. K., Rasul, S., Hasan, M. (2020) Weed management and crop performance of rice as influenced by different crop residues. *Archives of Agriculture and Environmental Science*, 5(3): 275–282. https://doi.org/10.26832/24566632.2020.050307

Safina, S., Mahmoud, R. (2017) Broadleaf weed control with some recent post-emergence herbicides in bread wheat (Triticum *aestivum* L.) in Egypt. *Egyptian Journal of Agronomy*, 39(1): 41–50. https://doi.org/10.21608/agro.2017.554.1054

Salma, M., Salam, M., Hossen, K., Mou, M. (2017) Effect of variety and planting density on weed dynamics and yield performance of transplant aman rice. *Journal of Bangladesh Agricultural University*, 15(2): 167–173.

Sarker, B. S., Uddin, M. R., Anwar, M. P., Sarker, U. K., Rasul, S. (2020) Effect of sunflower crop residues on weed management in transplanted aman rice. *Journal of Bangladesh Agricultural University*, 18(3): 557–564.

Sarker, D., Uddin, M. R., Paul, S. K., Sarker, U. K., Ahmed, F., Pramanik, S., Chadny, D. N. (2021) Aqueous extract of mustard crop residues on weed management and crop performance of wheat. *SAARC Journal of Agriculture*, 18(2): 17–26.

Sarker, U. K., Kaysar, M. S., Nahar, J., Uddin, M. R. (2022) Reduction in use of herbicides by combining aqueous extract of grass pea for weed management and yield of wheat. *Archives of Agriculture and Environmental Science*, 7(1): 97–103.https://doi.org/10.26832/24566632.2022.0701014

Sheikh, M. A. H., Uddin, M. R., Salam, M. A., Sarker, U. K., Haque, M. A. (2017) Weed suppression and crop performance of rice as influenced by application of different crop residues. *Journal of Fundamental and Applied Agriculture*, 2(1): 207–211.

Tonni, N. H., Sarker, U. K., Ahmed, M. T., Upama, S. A., Rahman, M. M., Uddin, M. R. (2024) Relative benefits of aqueous extract of sorghum residues with herbicide on weed control and yield of wheat varieties. *Journal of Bangladesh Agricultural University*, 22(3): 326–334. https://doi.org/10.3329/jbau.v22i3.76405

Uddin, M. R., Pyon, J. Y. (2010) Herbicidal activity of rotation crop residues on weeds and selectivity to crops. *Journal of Agricultural Science*, 37: 1–6.

Uddin, M. R., Won, O. J., Pyon, J. Y. (2010) Herbicidal effects and crop selectivity of sorgoleone, a sorghum root exudate under greenhouse and field conditions. *Korean Journal of Weed Science*, 30(4): 412–420.

Won, O. J., Uddin, M. R., Park, K. W., Pyon, J. Y., Park, S. U. (2013) Phenolic compounds in sorghum leaf extracts and their effects on weed control. *Allelopathy Journal*, 31(1): 147–156.

Zeidali, E., Hussein, K., Hatami, A., Lahmood al-issawi, N. R. (2025) Effect of wheat density and herbicides application on lolium (*Lolium Temulentum* L) control and grain yield under South Iraq conditions. *Egyptian Journal of Agronomy*. *In press*. https://doi.org/10.21608/agro.2025.354624.1619

Zinnat, M., Ahmed, M. T., Sarker, U. K., Rahman, M., Salam, M. A., Uddin, M. R. (2024) Influence of grass pea residues extract on weed control efficacy and performance of Boro rice. *Journal of Bangladesh Agricultural University,* 22(3): 360–368. https://doi.org/10.3329/jbau.v22i3.76409